Design and Fabrication of ZnO based energy harvesting MEMS Structures

A

SYNOPSIS/RESEARCH PROPOSAL

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FACULTY OF ENGINEERING AND TECHNOLOGY,

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FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

MEMS

by

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I. INTRODUCTION

With recent growth in the development of low-power electronic devices such as microelectronics and wireless sensor nodes, as well as the global interest in the concept of "green" engineering, the topic of energy harvesting has received much attention in the past decade. The energy requirements of low-power electronics have steadily decreased with advancements in efficient circuitry such that energy harvesting systems can be considered feasible solutions in providing power to self-powered systems. Conventional low-power electronics, such as wireless sensor nodes, rely on batteries to provide power to the device. The use of batteries, however, presents several drawbacks including the cost of battery replacement as well as limitations imposed by the need of convenient access to the device for battery replacement purposes. Wireless sensor nodes, for example, are often used in remote locations or embedded into a structure; therefore, access to the device can be difficult or impossible. By scavenging ambient energy surrounding an electronic device, energy harvesting solutions have the ability to provide permanent power sources that do not require periodic replacement. Such systems can operate in an autonomous, self-powered manner, reducing the costs associated with battery replacement, and can easily be placed in remote locations or embedded into host structures.

Energy harvesting is the process of converting available ambient energy into usable electrical energy through the use of a particular material or transduction mechanism. Several classes of material exist with various conversion mechanisms that can be used to harvest energy. Recent advancements in micro electro mechanical system (MEMS) technology has shown considerable progress towards self-powered energy sources by scavenging energy from ambient environments (solar, thermal, mechanical vibration) and enables the integration of self-powered devices, whose energy is harvested from the environment, in micro-packages and integrated circuits.

Some of the common materials include those with photovoltaic coupling to convert solar energy to electric energy, thermoelectric coupling to convert temperature gradients into electrical energy, and electromechanical coupling to convert mechanical vibration energy into electrical energy. Of the various modes of energy harvesting, vibration energy harvesting is the most versatile technique being developed in the literature. Three main mechanisms of vibration-to-electrical energy conversion exist including electrostatic, electromagnetic, and piezoelectric transduction. Review articles highlighting work

performed on all of the transduction mechanisms are given by Beeby et al. [1] and Cook-Chennault et al. [2]. Of the three modes of vibration harvesting, piezoelectric energy harvesting has received the most attention, with three review articles dedicated to recent research on piezoelectric transduction [3–5].

Piezoelectric vibration harvesting is attractive mainly due to the simplicity of piezoelectric transduction and the relative ease of implementation of piezoelectric systems into a wide variety of applications. One could wonder how efficient electronics and machines would become and the corresponding reduction in energy needs on a large scale if every device needing power could only rely on its immediate environment.

There are certain materials that can generate an electric charge or voltage when they are under mechanical stress; this is direct effect of piezoelectricity. Alternately same materials are able to produce a mechanical deformation (or force) when an electric field is applied to them, this is inverse/converse effect of piezoelectricity. In the last decade or so, nanostructured Zinc Oxide (ZnO) has drawn worldwide attention for its pathbreaking properties. One of its most extensively studied properties is its ability to generate power when subjected to mechanical vibration. It can generate a potential within a wide range of frequency vibrations, from a few Hz to thousands of KHz.

II. LIETRATURE REVIEW:

Over the past decade, a vast amount of research has been performed on the topic of vibration energy harvesting using piezoelectric materials. An overview of some of the pertinent studies has been presented in this section. Roundy [6] studied the energy conversion of ambient vibrations to electricity, which is based on both piezoelectric and electrostatic (capacitive) coupling. By comparing the power densities between piezoelectric converters and electrostatic converters, he concluded that piezoelectric converters are capable of higher power output densities. However, electrostatic converters are more easily implemented in silicon micromachining processes. Sodano et al. [3] published a review article highlighting the previous literature on piezoelectric vibration harvesting. Beeby et al. [1] published a review article highlighting previous works on piezoelectric, electrostatic, and electromagnetic harvesting for micro-scale applications. Priya [5] provided an overview of vibration harvesting using piezoelectrics, and Anton and Sodano [4] published a review of piezoelectric energy harvesting from 2003-2006 as an

update to the previous work by Sodano et al. [3]. L. Mateu and F. Moll [7] presented several different energy transducers for obtaining electrical energy from different types of energy available, including kinetic energy (piezoelectric generator, electrostatic energy generator and magnetic induction generator), electromagnetic radiation (solar energy, RF radiation) and thermal energy. Cook-Chennault et al. [2] provided an overview of various energy harvesting sources for MEMS applications including solar harvesting, thermal harvesting, and vibration harvesting using electrostatic, electromagnetic, and piezoelectric devices. Xudong Wang [8] published a paper reviewing the development of NGs (Nano-generators) from the fundamental principles to theoretical predictions to practical devices. Compared to conventional piezoelectric material based mechanical energy harvesters, using NWs (Nanowires) would potentially improve the energy conversion efficiency, enhance the sensitivity to low-level mechanical energy sources, and extend the device lifetime. Leading by the research on ZnO NWs, NWs made from other piezoelectric materials, including $BaTiO_3$, PZT, and PVDF were also studied to reveal their mechanical energy conversation capability. Different designs of NG were implemented mostly based on ZnO NW arrays.

Action Nechibvute, Albert Chawanda and Pearson Luhanga [9] & Brijesh Kumar, Sang-WooKim [10] reviews the importance of energy harvesting using ZnO nanostructures, mainly focusing on ZnO nanostructure-based photovoltaics, piezoelectric nano-generators, and the hybrid approach to energy harvesting. Indrani Dakau [11] published a review article entitled "Piezoelectric Energy Generation and Harvesting at the Nano-Scale: Materials and Devices" and found that, throughout the reported research work done up until now, ZnO holds several advantages over other materials. Wen-Yang Chang & Cheng-Han Yang [12] investigates the piezoelectric harvesting efficiency of ZnO microstructures with various structural configurations for electromechanical nanogenerators using finite element method simulation.

Khaled S Ramadan, D Sameoto and S Evoy[13] provides an overview of piezoelectric polymers based on their operating principle. This includes three main categories: bulk piezoelectric polymers, piezocomposites and voided charged polymers. A comparison between the different piezoelectric polymers and common inorganic piezoelectric materials (PZT, ZnO, AlN and PMN–PT) is also provided in terms of piezoelectric properties. The use of piezopolymers in different electromechanical devices e.g. tactile sensors, energy harvesters, acoustic transducers and inertial sensors is also reviewed.

III. WORK PLAN AND METHODOLOGY:

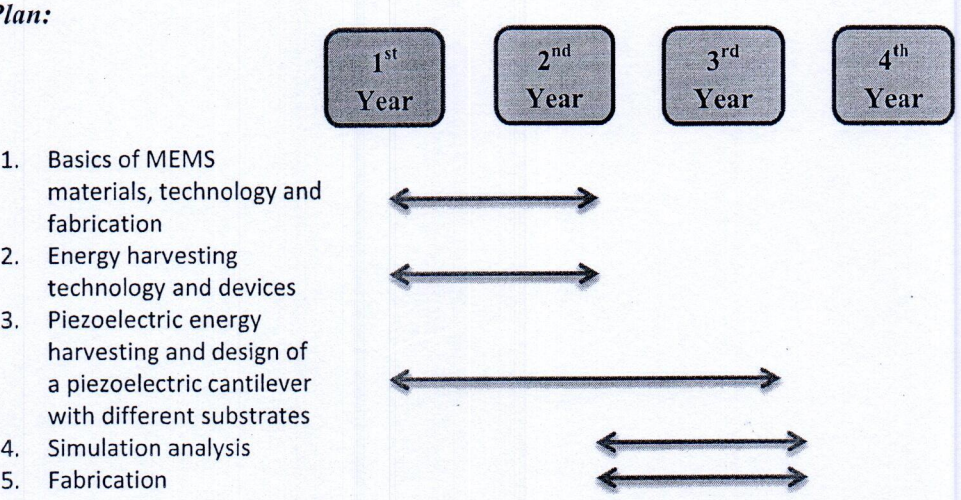
The proposed work is to design and fabricate a MEMS piezoelectric energy harvester. Zinc Oxide (ZnO) will be used as piezoelectric material. Initial activities will include designing piezoelectric cantilever beams. The design of the energy harvesters consists of a cantilever beam structure with the interdigitated electrodes on the Zinc Oxide piezoelectric layer that will be deposited on the substrate. After that, we will simulate the harvesting efficiency of piezoelectric ZnO microstructures using finite element method (FEM) simulation.

Simulation analysis will be done to simulate the resonance frequency since resonance frequency provides the maximum displacement of vibration and therefore maximum output will be produced. In addition, a model analysis will be conducted and the harmonic response of ZnO structures will be evaluated to illustrate the excitation frequency at maximum deflection. After getting best simulation results, device will be fabricated.

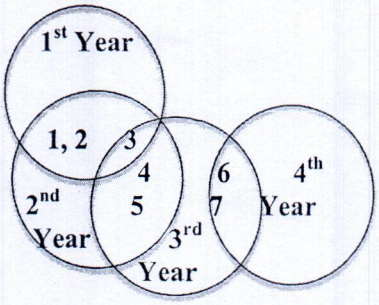
For ZnO thin film deposition onto the substrate, direct current or radio frequency reactive magnetron sputtering process from a Zn target will be used and it will be done with Reactive magnetron sputtering Unit manufactured by Hind High Vacuum Co. Pvt. Ltd., India.

We will make piezoelectric cantilever grown on different substrates such as Silicon (Si), Silicon Carbide (SiC) using different methods. The output potential from each piezoelectric energy harvester will be measured and compared under the same conditions.

Work Plan:


1st Year
2nd Year
3rd Year
4th Year
1. Basics of MEMS materials, technology and fabrication
2. Energy harvesting technology and devices
3. Piezoelectric energy harvesting and design of a piezoelectric cantilever with different substrates
4. Simulation analysis
5. Fabrication

6. Measurement of Output voltage and analysis
7. Thesis submission



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